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Paek

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(54) **TRUE TIME DELAY GENERATING SYSTEM AND METHOD**

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(52) **U.S. Cl.** **385/24**; 385/7; 385/37; 343/720; 343/721; 343/778; 359/130; 359/341

(58) **Field of Search** 385/24, 31, 37, 385/14, 7; 372/20; 343/720, 721, 778; 359/127, 130, 341

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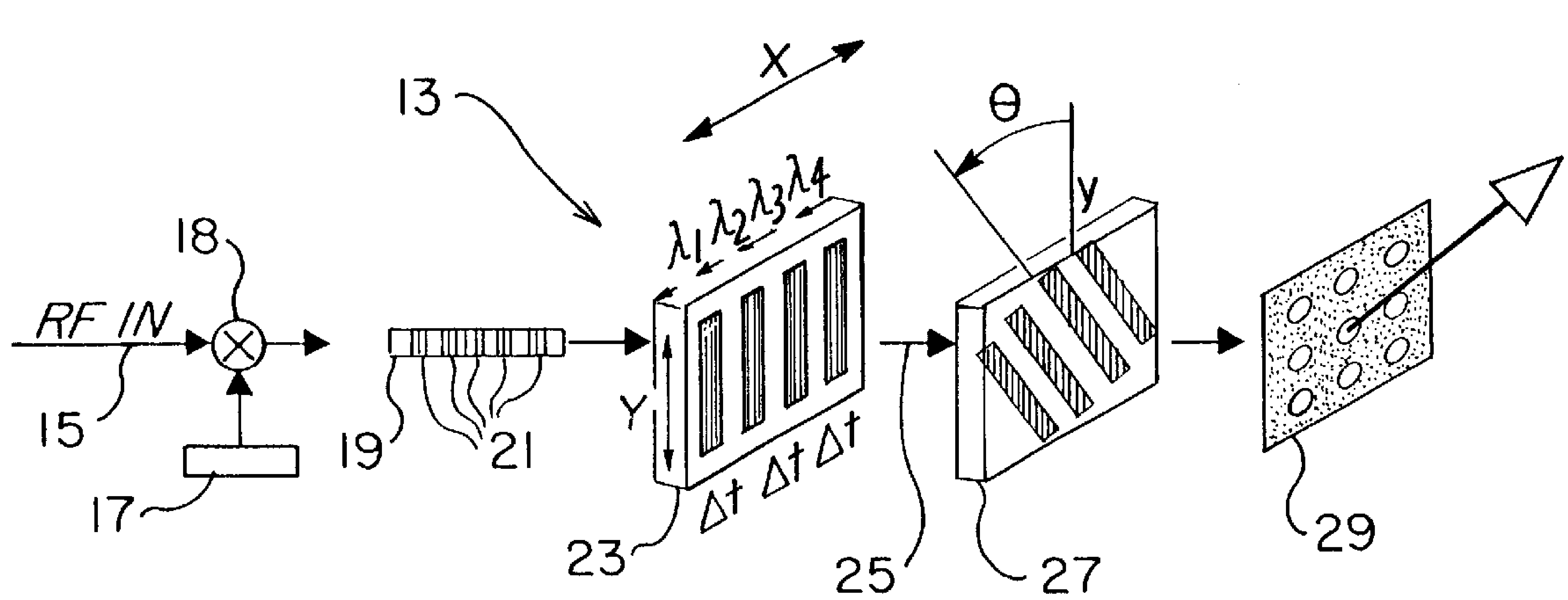
(57) **ABSTRACT**

System and method for rapidly reconfigurable two-dimensional true time delay generation for phased array antennas is described. The system utilizes a broadband light source, an array of fiber chirp gratings in a single fiber, and an acousto-optic spectrometer to generate a time-delayed linear grating. The grating is subsequently rotated to the desired angle utilizing an acousto-optic device having no moving parts.

18 Claims, 3 Drawing Sheets



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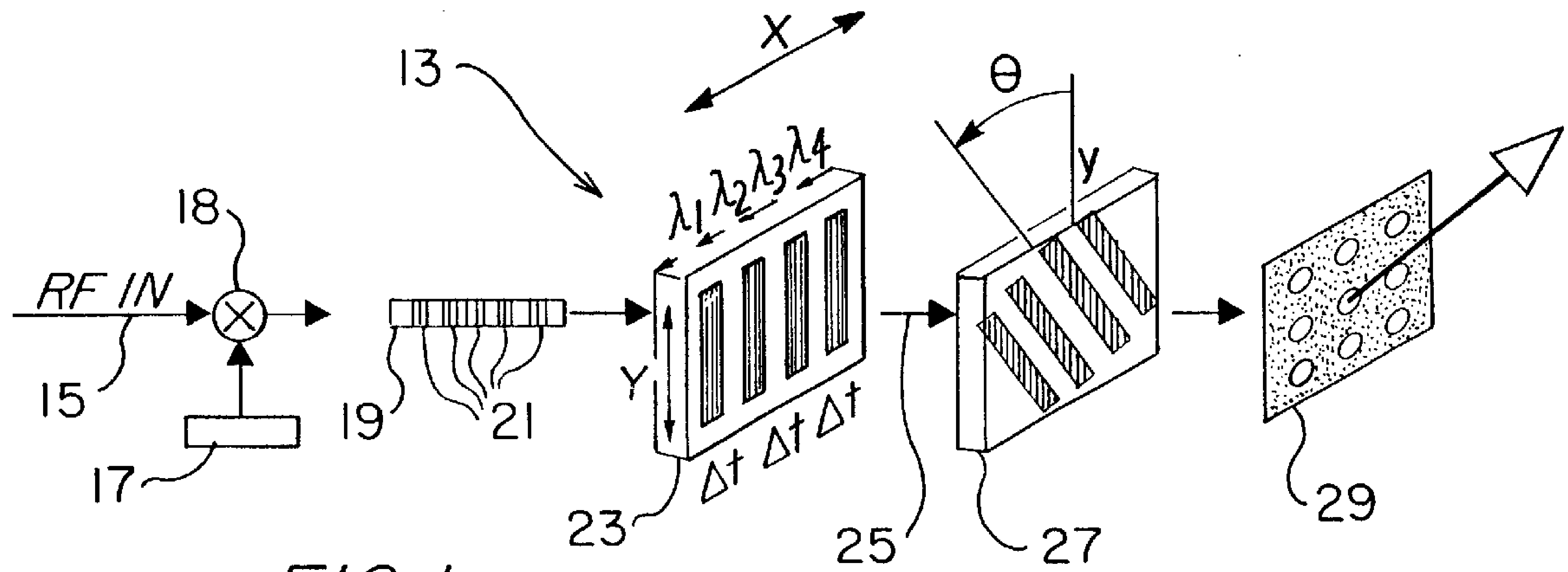
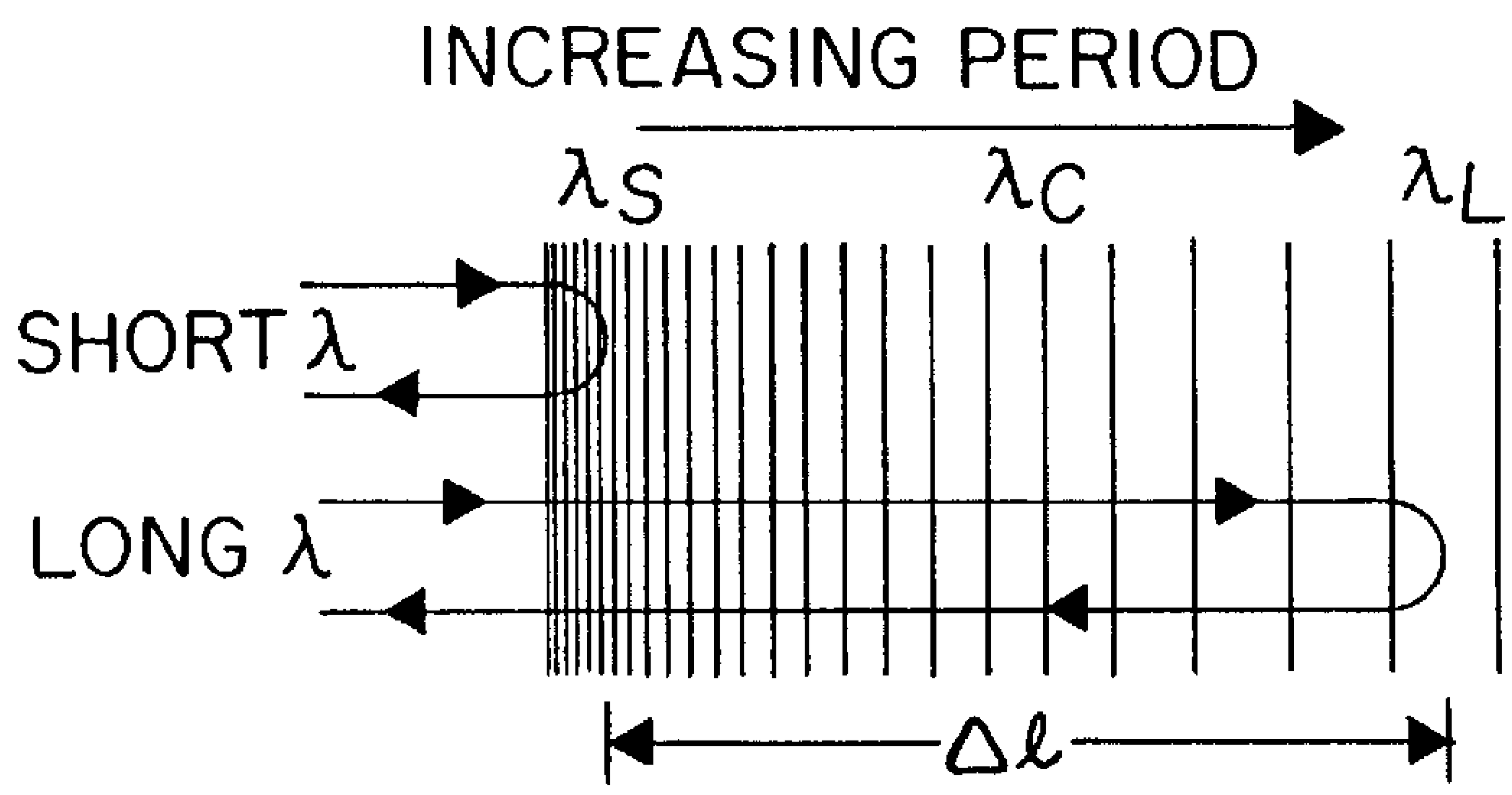
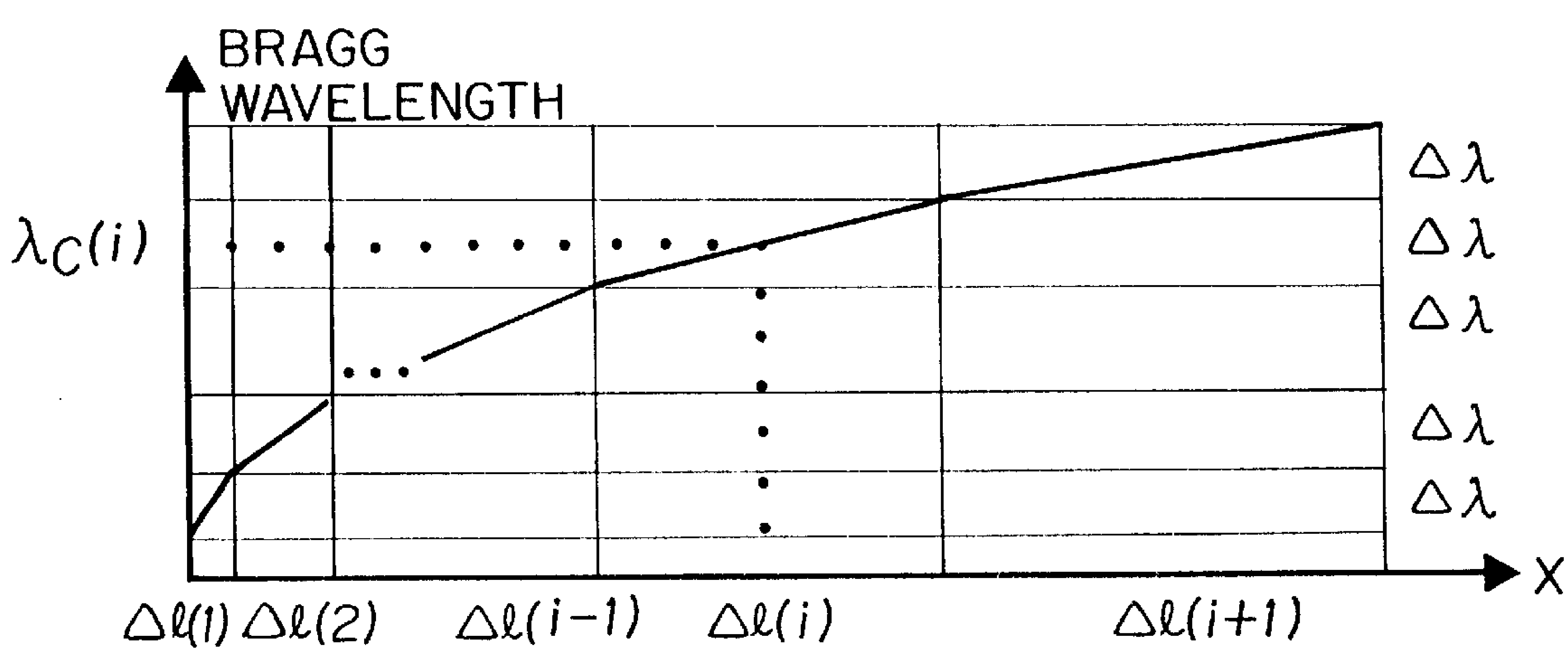

X
13
θ
y
λ1 λ2 λ3 λ4
18
RF IN
Y
Δt Δt Δt
15
19
21
17
23
25
27
29

F/G. 1


INCREASING PERIOD
λS
λC
λL
SHORT λ
LONG λ
Δℓ

F/G. 2


BRAGG
WAVELENGTH
λC(i)
Δλ
Δλ
Δλ
Δλ
Δλ
X
Δℓ(1) Δℓ(2)
Δℓ(i-1)
Δℓ(i)
Δℓ(i+1)

F/G. 5

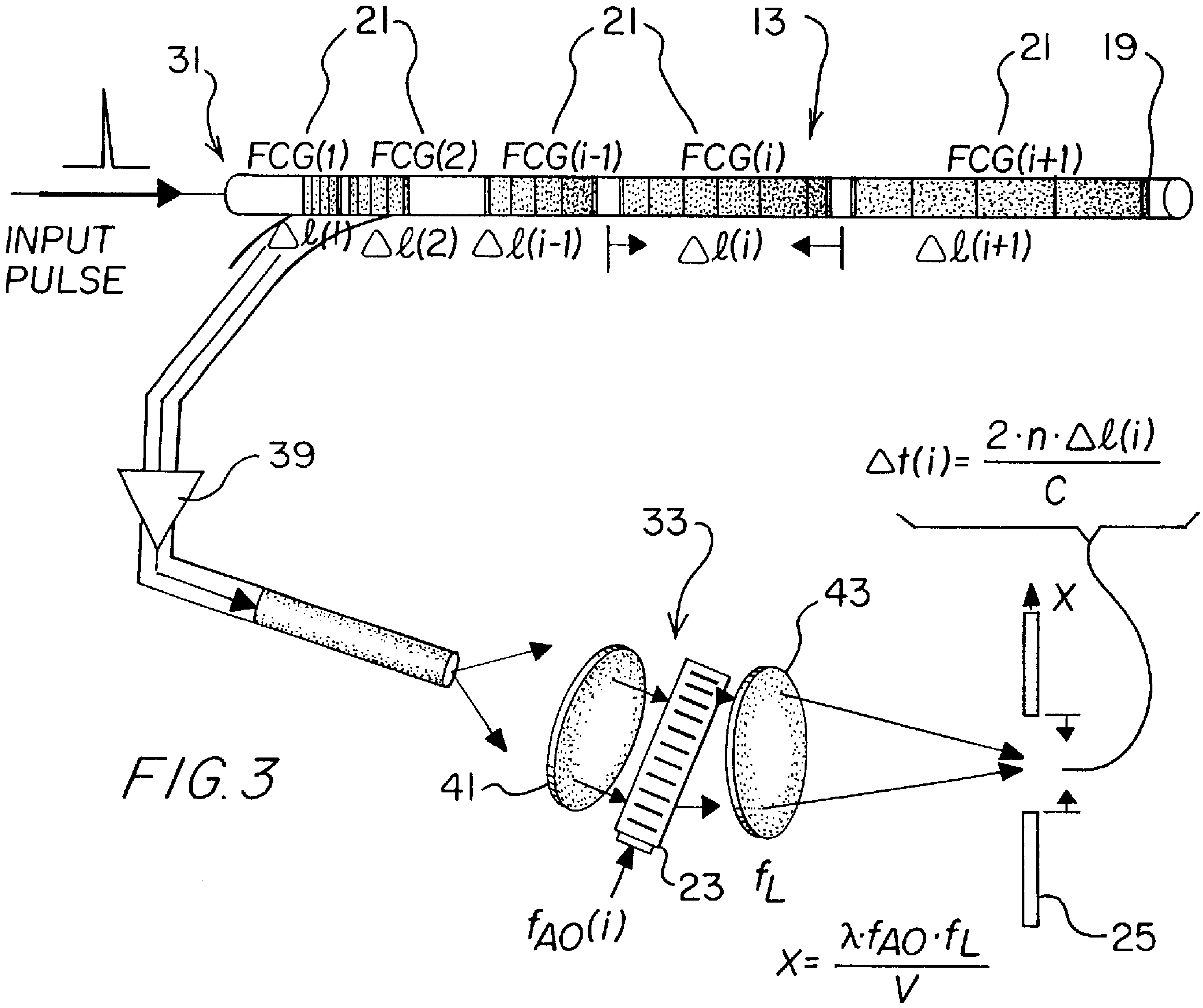

31
21
21
13
21
19
FCG(1)
FCG(2)
FCG(i-1)
FCG(i)
FCG(i+1)
INPUT PULSE
Δℓ(1)
Δℓ(2)
Δℓ(i-1)
Δℓ(i)
Δℓ(i+1)
39
Δt(i)= 2·n·Δℓ(i) / C
33
43
X
41
23
f_L
$f_{AO}(i)$
25
X= λ·fAO·fL / V

FIG. 3

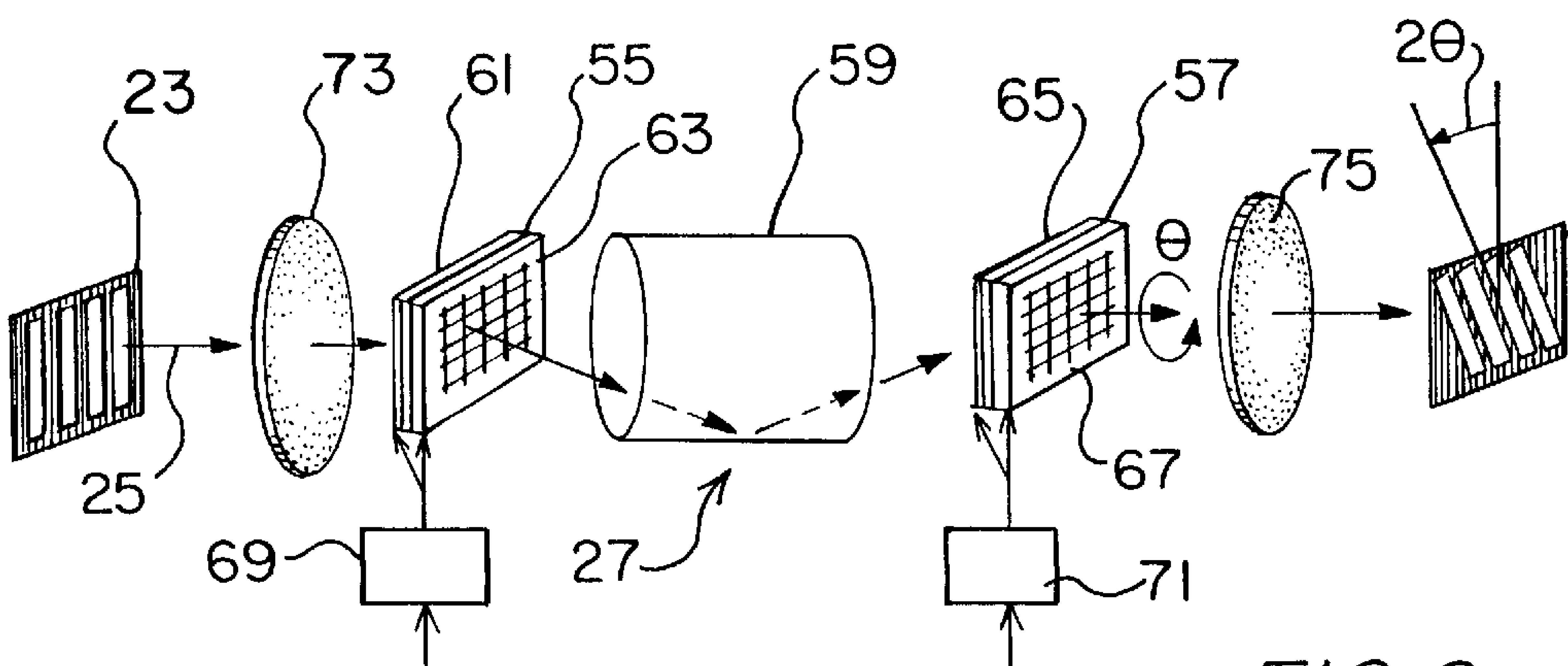

23
73
61
55
63
59
65
57
2θ
83
75
θ
25
69
27
67
71

FIG. 6

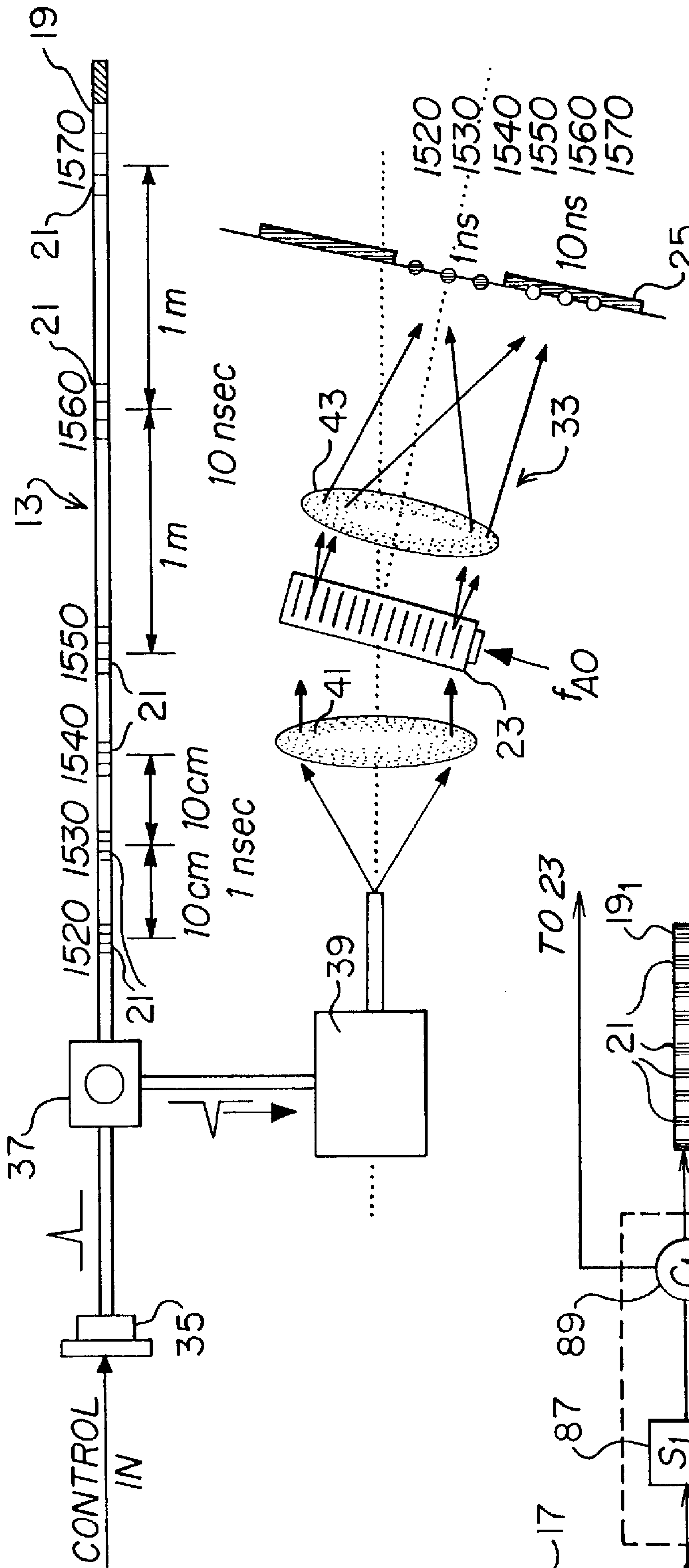
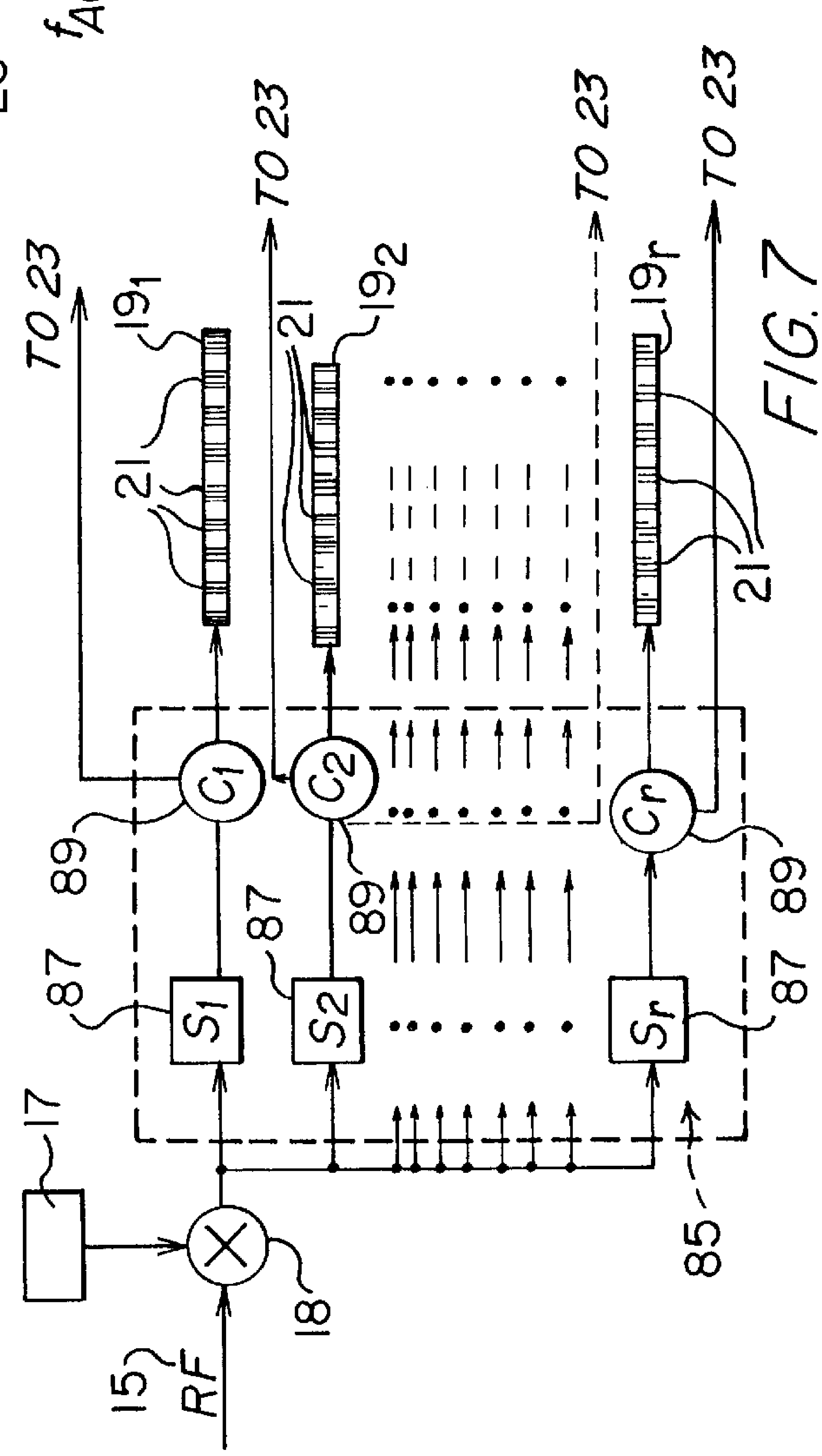

19
1570
21
1560
13
1550
1540
1530
1520
10cm 10cm
1 nsec
1m
1m
10 nsec
37
35
CONTROL IN
39
41
23
f_{AO}
43
33
1520
1530
1540
1550
1560
1570
1ns
10ns
25

FIG. 4


TO 23
TO 23
TO 23
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19_1
19_2
19_r
21
C_1
C_2
C_r
S_1
S_2
S_r
87
89
85
17
18
15
RF

FIG. 7

TRUE TIME DELAY GENERATING SYSTEM AND METHOD

RELATED U.S. PROVISIONAL PATENT APPLICATION

This application is a division of U.S. patent application Ser. No. 09/009,224 filed Jan. 20, 1998, now U.S. Pat. No. 6,295,395, and entitled TRUE TIME DELAY GENERATION UTILIZING BROADBAND LIGHT SOURCE WITH FIBER CHIRP GRATING ARRAY AND ACOUSTO-OPTIC BEAM STEERING AND 2-D ARCHITECTURE by Eung G. Paek.

FIELD OF THE INVENTION

This invention relates to phased array antenna systems, and, more particularly, relates to optical true time delay generation methods and architecture for such systems.

BACKGROUND OF THE INVENTION

The phased array antenna is one of the most advanced radar technologies which allows multiple beam pointing and fast non-mechanical steering of microwave beams. The technology has promise for broad-band (2–20 GHz) free-space radar communications that can be used for a variety of commercial and military applications. Beam pointing/steering control systems are known, including true time delay systems and phase shift systems, for phased array antenna, true time delay systems being preferable since the steered beam angle is independent of frequency and squint is eliminated.

For a given microwave frequency ▒ and number of microwave radiating elements along one direction N, the maximum time delay Δt_{max} required to steer a beam over ±90° is given by N/f. Also, the minimum temporal resolution $\Delta\tau_{min}$ to achieve resolution R is given by $1/(f \cdot R)$. Assuming a frequency range of 2–20 GHz, N=100 and R=1,000, Δt_{max}=5–50 nsec and $\Delta\tau_{min}$=0.05–0.5 psec.

In conventional electronic RF systems, true time delay is achieved using switched lengths of electrical waveguide or cable. Such devices tend to be bulky, expensive, have high loss at high frequencies, and are susceptible to electrical crosstalk (due to electromagnetic interference) and temperature induced time delay changes. Recent advances in photonic technology can provide a better implementation of true time delay due to a natural high parallelism and large bandwidth as well as immunity to electromagnetic interference.

Heretofore known or suggested photonic true time delay systems have been configured so that each microwave element requires R fixed time delay generators, R switches and an R to 1 combiner. Thus, for a two dimensional (2-D) array with N^2 elements in such systems, N^2R time delays and N^2R switches have been required. The insertion loss is mainly determined by the R to 1 combiner and is given by $10 \log_{10}R$. Although such a system is capable of adaptive beam forming as well as beam steering, it requires a tremendous amount of complexity, making its hardware implementation extremely difficult.

Although this complexity can be reduced to some degree by free-space path-switching methods, this still requires a cascaded array of many independent time-delay generators and parallel (N^2) switches in 2-D spatial light modulators. Moreover, thus configured, the system presents other limitations, such as speed and path-dependent insertion loss.

A highly dispersive fiber prism method has been suggested and/or utilized that can significantly reduce the

complexity as described above. However, this method requires very long (20 km for 1 GHz), N^2 fiber bundles and a fast tunable narrow linewidth light source with broad tuning range. It has been suggested that the long length could be significantly reduced by using an array of fiber gratings, but significant problems with this implementation would yet be posed. Most of the heretofore suggested approaches for use of fiber gratings as a means to generate true time delays employ an array of normal single frequency fiber gratings, the desired time delays being selected by a tunable narrow linewidth light source. To achieve high resolution, both a broad tuning range and a narrow linewidth are required. Moreover, the wavelength would need to be changeable rapidly (within a few microseconds—a speed unattainable by current laser technology) for effective implementation.

In addition, two dimensional (2-D) extension architecture for such photonic true time delay systems as have been heretofore suggested could utilize further improvements. Conventional image rotation has been accomplished, for example, by rotating a dove prism by an angle 0 around the optical axis, the output image thus being rotated by 20. Such conventional rotation thus requires mechanical movement of components and is, therefore, inherently slow and lacking adequate unreliability.

SUMMARY OF THE INVENTION

This invention provides a true time generating system and method for both one dimensional and two dimensional generation of time delayed gratings for use with phased array antenna systems. This invention includes a delay encoder operable with a broadband light source and utilizing a single optical fiber having an array of fiber chirp gratings therein, an optical signal decoding device for receiving a wavelength encoded light signal and providing as an output therefrom a time delayed grating, and image rotation utilizing acousto-optics and without moving mechanical parts.

The delay encoder fiber chirp gratings are configured so that different wavelengths of the light from the light source are reflected at unique locations at each individual fiber chirp grating, the locations corresponding to different selected time delays, thereby providing a wavelength encoded light signal output. The decoding device receives the wavelength encoded light signal output and utilizes this output to provide a time delayed linear grating as an output therefrom.

An optical amplifier amplifies the wavelength encoded light signal and an acousto-optic deflector having a variable acoustic signal input is positioned to receive the amplified light and disperse the light at selected diffraction angles variable by an acoustic signal at the input. A window is positioned at the output plane from the deflector for selection of an output spectrum from the dispersed light, spectrum selection controlled by diffraction angle selection at the acousto-optic deflector.

The method for generating true time delays of this invention includes the steps of launching broadband light into an optical fiber having a plurality of selectively located fiber chirp gratings therealong to provide a wavelength encoded light signal output. The light signal output is dispersed at selected diffraction angles to provide multiple wavelength spectra linearly arrayed at an output plane, a spectrum from the multiple wavelength spectra at the output plane corresponding to a selected one of the fiber chirp gratings at said optical fiber being selected thereby providing a selected time delayed linear grating.

Utilizing this invention, the complexity of heretofore known systems can be significantly reduced, requiring only a number of fiber chirp gratings in a single fiber providing the number of different time delays desired. The compact system allows a broad range of time delays that can be reconfigured within a few microseconds, and because of fewer or no mechanical elements and switches, is inherently more reliable.

It is therefore an object of this invention to provide true time delay generation systems and method utilizing a broadband light source and a fiber chirp grating array in a single fiber.

It is another object of this invention to provide true time delay generation systems and method including fully optical delay selection and acousto-optic image rotation.

It is another object of this invention to provide optical true time delay generation systems of reduced complexity, requiring only a number of fiber chirp gratings in a single fiber providing the number of different time delays desired.

It is still another object of this invention to provide true time delay generation systems for phased array antenna systems which are compact, allow a broad range of time delays that can be reconfigured within a few microseconds, and are highly reliable.

It is still another object of this invention to provide a true time delay generating system including a broadband light source, delay encoding means including an optical fiber for receiving light from the broadband light source, the optical fiber having at least a first selectively located fiber chirp grating defined therein so that different wavelengths of the light from the light source are reflected at unique locations at the fiber chirp grating, the locations corresponding to different selected time delays, thereby providing a wavelength encoded light signal output, and decoding means for receiving the wavelength encoded light signal output and utilizing the wavelength encoded light signal output to provide a time delayed linear grating as an output therefrom.

It is yet another object of this invention to provide a true time delay generating system including a broadband light source, delay encoding means including an optical fiber for receiving light from the broadband light source, the optical fiber having at least a first selectively located fiber chirp grating defined therein so that different wavelengths of the light from the light source are reflected at unique locations at the fiber chirp grating, the locations corresponding to different selected time delays, thereby providing a wavelength encoded light signal output, and decoding means for receiving the wavelength encoded light signal output and utilizing the wavelength encoded light signal output to provide a time delayed linear grating as an output therefrom, the decoding means including an acousto-optic deflector for light dispersion at diffraction angles selectable by variation of an input signal.

It is still another object of this invention to provide an optical signal decoding device for receiving a wavelength encoded light signal and providing as an output therefrom a time delayed grating for utilization in a phased array antenna system, the device including an acousto-optic deflector for receiving an amplified light signal and dispersing the light signal at selected diffraction angles to an output plane, and a window at the output plane for selection of an output spectrum from the dispersed light signal.

It is yet another object of this invention to provide a method for generating true time delays including the steps of launching broadband light into an optical fiber having a plurality of selectively located fiber chirp gratings therealong to provide a wavelength encoded light signal output, dispersing the wavelength encoded light signal output at selected diffraction angles to provide multiple wavelength spectra linearly arrayed at an output plane, and selecting a spectrum from the multiple wavelength spectra at the output plane corresponding to a selected one of the fiber chirp gratings at the optical fiber to thereby provide a selected time delayed linear grating.

With these and other objects in view, which will become apparent to one skilled in the art as the description proceeds, this invention resides in the novel construction, combination, arrangement of parts and method substantially as hereinafter described, and more particularly defined by the appended claims, it being understood that changes in the precise embodiment of the herein disclosed invention are meant to be included as come within the scope of the claims.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings illustrate a complete embodiment of the invention according to the best mode so far devised for the practical application of the principles thereof, and in which:

FIG. **1** is a schematic illustration of a 2-d true time delay generation system architecture in accord with this invention;

FIG. **2** is a chart illustrating fiber grating position and Bragg wavelength correlation;

FIG. **3** is a functional illustration of the time delayed linear grating generation system of this invention including encoding and decoding;

FIG. **4** is another functional illustration of the system substantially in accord with FIG. **3**;

FIG. **5** is a chart illustrating Bragg wavelength distribution along the fiber with reference to FIGS. **2** and **3**;

FIG. **6** is a functional illustration of acousto-optic image rotation architecture in accord with this invention; and

FIG. **7** is a functional illustration of another embodiment of the system of this invention.

DESCRIPTION OF THE INVENTION

True time delay control architecture **13** of this invention for generation of a one dimensional (1-D) diffraction grating light pattern whose period (temporal time delay in the true time delay case) and orientation (2-D extension) can be changed rapidly is schematically illustrated in FIG. **1**. As may be appreciated from FIG. **1**, the complexity of this true time delay system is significantly reduced compared with conventional systems in which provision for all the possible delays are required for each microwave radiating element of a phased array antenna system.

In FIG. **1**, RF input signal **15** is modulated by CW light source **17** at electro-optic modulator **18** providing light having a broad spectral linewidth (for example, 50 nm), and is launched into single optical fiber **19** having an array of fiber chirp gratings **21** defined therealong (see FIG. **3**). Formation of such gratings in optical fiber may be done using known techniques. Each fiber chirp grating **21** defined in fiber **19** has a unique chirp ratio, and thus defines unique time delays. The light from each fiber chirp grating is dispersed along the x direction, or axis, by acousto-optic beam deflector **23** and is stretched along the y direction, or axis.

By adjusting the frequency of acoustic signal applied to acousto-optic beam deflector **23** (for example, using an rf signal adjustable in a range from 30 MHz to 60 MHz under program control to an rf generator or frequency synthesizer), the spectrum from the desired fiber chirp grating **21** is selected and positioned on output window **25**. The time-delayed grating thus obtained is subsequently rotated to the desired angle by ultrafast image rotator **27** before output at N×N light to microwave converters **29**. In the following, a more detailed explanation the 1-D true time delay system of this invention and its extension to a 2-D case in accord with this invention is provided.

In the system of this invention, an array of equally spaced N time delays is generated by a single fiber chirp grating **21**. As shown in FIG. **2**, the Bragg wavelength of a fiber chirp grating varies linearly as a function of position, from λ_S to λ_L with the center wavelength λ_C, over the length Δl. The wavelength chirp ratio $r=\Delta\lambda/\Delta l$, $(\Delta\lambda=\lambda_L-\lambda_S)$, is kept constant within a fiber chirp grating. The resultant relative time delays arising from various portions (i.e., single frequency fiber Bragg gratings) of the fiber chirp grating distribute uniformly ranging from 0 to the maximum value $\Delta t=2\cdot\eta\cdot\Delta l/C$, where η is the refractive index of the fiber core and C is the speed of light in vacuum. Each of these time delays is encoded by the corresponding wavelength, while keeping the ratio $\Delta t/\Delta\lambda$ constant.

One should also note that fiber chirp gratings can be superposed to reduce the total fiber length owing to the phase matching selection property of a volume grating, as long as the total refractive index change does not exceed the maximum limit of the fiber. When the fiber chirp grating is long, it can be discretized to form an array of N short sinusoidal gratings.

The 1-D true time delay control system of this invention includes fiber chirp grating encoder architecture **31** and acousto-optic spectrometer decoder architecture **33** as shown in FIGS. **3** and **4** (each illustrating different aspects of and/or alternatives for the implementation of this invention). Both encoding and decoding are achieved by wavelengths. Fiber chirp grating encoder **31** includes a light pulse generator (either 17/18 as shown in FIG. **1** or utilizing another broadband source such as LED **35** (FIG. **4**), or an amplified spontaneous emission source, modulated by an external electro-optic modulator) with broad spectral bandwidth and single fiber **19** (terminated at one end) with an array of fiber chirp gratings **21** in it. Light is circulated at circulator **37** in a conventional fashion (see FIG. **4**).

FIG. **5** (referring to FIGS. **2** and **3**) illustrates Bragg wavelength distribution inside fiber **19** as a function of position. The i th fiber chirp grating **21** has the length $\Delta l(i)=\Delta l(\mathbf{1})\cdot i$, and all fiber chirp gratings **21** have the same amount of wavelength bandwidth, $\Delta\lambda(i)=\Delta\lambda_{FCG}$=constant. Therefore, the wavelength chirp ratio of the i th fiber chirp grating **21**, r(i), is given by the relation $r(i)=r(\mathbf{1})/i$, (or $\Delta t(i)=i\cdot\Delta t(\mathbf{1})$, where r(**1**) and Δt(**1**) are defined for the first fiber chirp grating **21**.

If light from pulsed source **35** (or, alternatively, CW source **17**, or the like, modulated by electro-optic modulator **18** using pulsed microwave signal **15** as shown in FIG. **1**) with a wide spectral bandwidth, $\Delta\lambda_{SC}$, is launched into fiber **19**, each particular wavelength of the input light is reflected at a corresponding unique fiber chirp grating **21** location to give the desired time delay. In this way, each time delay is encoded by the corresponding wavelength.

The wavelength encoded light signal output from circulator **37** is optically amplified in a single fiber channel by erbium doped fiber amplifier **39** (or an equivalent means of amplification), and is connected with free space acousto-optic spectrometer decoder **33** including spherical lenses **41** and **43** and acousto-optic beam deflector **23**. Acousto-optic spectrometer decoder **33** disperses the incoming light like a normal prism, the primary difference between acousto-optic spectrometer decoder **33** and a normal prism being that the diffraction angle can be rapidly (within a few microseconds) varied by simply changing the acoustic frequency applied to acousto-optic beam deflector **23**. In acousto-optic spectrometer decoder **33**, the light with wavelength λ is focused to a point separated from the optical axis by $x=\lambda\cdot f_{AO}\cdot f_L/V_{AO}$, where f_{AO}, f_L and V_{AO} represent acoustic frequency applied to acousto-optic beam deflector **23**, focal length of lens **41** and acoustic velocity inside the acoustic medium (for example, focal length of lenses **41** and **43** are typically about 5 cm and 20 cm, respectively, and acoustic velocity is typically about 600 m/s in the medium). The spatial extent of the spectrum generated by each fiber chirp grating **21** is given by $\Delta x=\Delta\lambda\cdot f_{AO}\cdot f_L/V_{AO}$.

The temporal delay over each spectrum is $\Delta t(i)=\mathbf{2}\cdot\eta\cdot\Delta l(i)/C$ Since Δt Δλ and Δx Δλ, it follows that Δx Δt. In other words, time delay is uniformly distributed along x providing a suitably time delayed linear grating. At the output plane, window **25** is placed to select the spectrum from the desired fiber chirp grating only. By varying the acoustic frequency ▒ such that $f_{AO}(i)\cdot\lambda_C(i)$=constant, the desired i th spectrum can be centered at output window **25** (other spectra being centered at the window by adjusting the frequency accordingly; see FIG. **4**).

Also, multiple beam forming can be easily achieved by applying many acoustic sinusoidal frequencies simultaneously to acousto-optic beam deflector **23**, without the need for any hardware changes. Window **25** is characterized by a slit with an aperture size of about 0.5 mm to 5 mm depending upon the number of radiating elements.

In this way, time delays encoded to wavelengths in encoder **31** are decoded back to time delays. Owing to fiber chirp gratings **21** and acousto-optic spectrometer decoder **33** combined with output window **25**, N element encoding/decoding is achieved simultaneously in parallel in a simple and compact free space system. One great advantage of this free space spreading over the heretofore known dispersive fiber method is that it can avoid the complicated N^2 long fiber bundles. In addition, adequate room for optical amplification or means for compensation for misalignment due to temperature changes remains without making the system overly cumbersome. The compact 1-D decoder **33** of this invention can also be integrated using integrated waveguide optics.

The components utilized above may be any of those known to skilled practitioners in the art. For example, modulator **18** may be a Mach-Zehnder electro-optic modulator or multiple-quantum-well based electro-absorptive modulator, and fiber **19** may be formed from optical fiber having germania-doping to increase light sensitivity. Circulator **37** may be a three port device using Faraday isolators to allow reverse signal entering one of the two output ports to be transmitted to the other output port as a usable signal while being completely isolated from the input signal, fiber amplifier **39** is an Erbium-doped amplifier, and lenses **43** are preferably spherical lenses with doublet elements to reduce aberrations. Acousto-optic beam deflector **23** is preferably characterized by large time-bandwidth product (defined by aperture time multiplied by the frequency bandwidth; more than 1,000) and high diffraction efficiency (for instance, utilizing slow shear-mode TeO_2 material; more than 30% efficiency preferred) at the 1.55 micron wavelength region.

The above-described 1-D true time delay system could be extended to the 2-D case by cascading as heretofore known.

In such case, advantages remain in that only N+1 fibers, as opposed to N^2 fibers utilized by previous systems, would be required. Moreover, the free space acousto-optic spectrometer **33** can be shared among N elevation elements (typically up to at least about 1,000).

However, a better means in accord with this invention for extending to 2-D true time delay, and which significantly reduces complexity because of elimination of moving parts, provides ultrafast image rotation utilizing acousto-optic image rotator **27** (a dove prism-like arrangement) as shown in FIG. **6**. The system includes a pair of xy-acousto-optic beam deflectors **55** and **57** and circular cylindrical mirror **59** to generate the required inversion operation.

In principle, the rotating wedge prism portions of a conventional dove prism have been replaced by xy-acousto-optic beam deflectors **55** and **57**, each consisting of a pair of acousto-optic beam deflectors **61**/**63** and **65**/**67**, respectively, sandwiched together with transducers along orthogonal directions (slow shear mode TeO_2 crystals could be utilized; however, a more compact (10 mm×10 mm×2 mm) crossed deflector with both transducers on the same crystal is preferable). By adjusting the frequencies of acoustic signals applied to the acousto-optic beam deflector pairs **61**/**63** and **65**/**67**, beam direction can be changed along arbitrary directions, just as a wedge prism does. Since circular cylindrical mirror **59** is rotationally symmetric, its rotation is not required. However, to prevent unwanted mirror distortion owing to the curvature of the circular mirror surface, the cylindrical mirror is preferably discretized to multiple facets. Also, incoming light is focused to have a minimum size on the mirror surface. Therefore, by simply varying the acoustic frequencies, an image can be rotated to arbitrary selected angles, without any moving parts while yet preserving optical transparency.

The rotation angle of an image output from window **25** can be reconfigured (for example, rotated by 180°) within a few microseconds in a programmable manner utilizing frequency synthesizers **69** and **71** (for example, a frequency synthesizer with a frequency sweep range of 30 MHz to 70 MHz, with frequency accuracy of less than 1 Hz and drive output power of up to 1 watt, interfaced with a PC for with fast parallel connectors to allow fast access time, preferably on the order of microseconds). To prevent the unwanted distortion owing to the curvature of the circular mirror surface, the cylindrical mirror is discretized to multiple facets. Also, incoming light is focused to have a minimum beam size on the mirror surface by using lens **73**. Lens **75** is used to form an image at output plane **83** (for example, lenses **73** and **75** are spherical doublet lenses having a 20 cm focal length and opposite orientation to compensate for the aberration with each other). Special lens designs could, alternatively, be conceived to compensate for the fixed distortion due to the circular cylindrical mirror surface. It should be recognized that lenses **73** and **75** as shown in the FIGURE could be alternatively positioned relative to beam deflectors **55** and **57**, respectively, with each positioned adjacent to opposite ends of mirror **59**.

In operation, light representing the time delayed linear grating is located at the front focal plane of lens **73**, and is deflected by the crossed acousto-optic beam deflector pair **55** to a selected output angle under control of the acoustic signal input. At the deflected angle, the light is focused on the surface of cylindrical mirror **59**. After reflection thereat, the light is deflected again by crossed acousto-optic beam deflector pair **57** (again under control from program controlled frequency synthesizer **71** output acoustic signal) forming a selectively rotated image at output plane **83** (to N×N light to microwave converters **29** of FIG. **1**).

The system described hereinabove provides significant advantage over now known conventional systems. For example, conventional systems, including highly dispersive fiber delay systems, require significantly more time delay generators switches and/or fiber bundles (and/or significantly greater fiber length, i.e., translating into much greater total fiber volume) than is required for this invention. These advantages are summarized in Table 1.

TABLE 1

Complexity of various systems: (1) Conventional Photonic Systems, (2) Highly Dispersive fiber systems, and (3) this invention; where N = elements along one direction and R = resolution (Note: 10 cm × 10 cm × 1000 is approximated to 3 m × 3 m)

	Conventional (1)	HD Fiber (2)	Proposed FCG/AOBD (3)
# Delays	N^2R	N^2	NR
# Switches	N^2R	2	2
# Bundles	N^2	N^2	1
# Splitters (1 to N)	$2N^2$	N + 1	0
100 nsec length	20 m	20 Km	10 m
Total fiber volume	3 m × 3 m × 20 m = 180 m^3 (4)	0.1 × 0.1 × 20,000 = 200 m^3	0.001 × 0.001 × 10 = 10^{-5} m^3

The maximum number of wavelength channels (or time delays) in the architecture of this invention is determined by such factors as the passband of fiber amplifier **39** (typically 50 nm), the bandwidth of an FBG (i.e., fiber Bragg grating, for example, typically 0.04 nm for a 10 cm long FBG) and the resolution of acousto-optic spectrometer **33**. Normally, more than 1,000 time delays can be generated utilizing the invention as illustrated heretofore.

For dense systems, requiring significantly more than 1,000 different time delays (for example up to at least about 10,000), multiplexing architecture **85** as shown in FIG. **7** may be employed, for example, using r optical switches **87** and r circulators **89** in conjunction with r fibers **19** having fiber chirp gratings **21** therein (r equalling the selected extensions required to achieve the desired number of time delays). In this case, fiber chirp gratings **21** are distributed in several fibers and the desired fiber is selected by the corresponding optical switch **87** (for example, under program control from a PC). Even for the system shown in FIG. **7**, the number of switches required is determined by the multiplexing number (typically 10) instead of Nr (typically 1,000) to N^2R (typically 10^7) as would heretofore have been required in conventional systems. An alternative way of multiplexing using optical switches is to employ the conventional binary fiber optical delay line concept by cascading the fibers in series.

As may be appreciated from the foregoing, true time delay control utilizing a specially designed array of fiber chirp gratings in a single fiber with a broadband light source input, and that requires no intermediate photon-to-electron conversion processes, is provided for phased array antenna systems. Each fiber chirp grating in the array is designed to provide a unique linear chirp ratio, and wavelengths do not overlap. Generation of time delays from wavelengths (i.e., utilizing the decoder of this invention) is rapidly accomplished along a wide tuning range and provides a tailored array of selected linear chirp time delays in parallel. 2-D extension is accomplished with far fewer elements than heretofore known and with no moving parts.

What is claimed is:

1. A true time delay generating system comprising:

a broadband light source;

delay encoding means including an optical fiber for receiving light from said broadband light source, said optical fiber having at least a first selectively located fiber chirp grating defined therein so that different wavelengths of said light from said light source are reflected at unique locations at said fiber chirp grating, said locations corresponding to different selected time delays, thereby providing a wavelength encoded light signal output; and

decoding means for receiving said wavelength encoded light signal output and utilizing said wavelength encoded light signal output to provide a time delayed linear grating as an output therefrom.

2. The true time delay generating system of claim **1** further comprising a plurality of selectively positioned second fiber chirp gratings defined in said optical fiber of said delay encoding means.

3. The true time delay generating system of claim **2** wherein said decoding means includes means for spectrum selection as said time delayed linear grating, selected spectrum corresponding to a selected fiber chirp grating time delays.

4. The true time delay generating system of claim **2** wherein wavelength chirp ratio is constant within any one of said fiber chirp gratings, with each different said fiber chirp grating having a unique wavelength chirp ratio.

5. The true time delay generating system of claim **1** wherein said broadband light source provides either one of a pulsed or rf modulated broadband light output.

6. The true time delay generating system of claim **1** wherein said delay encoding means includes a circulator connected with said optical fiber and having as an output therefrom said wavelength encoded light signal output.

7. A true time delay generating system comprising:

a broadband light source;

delay encoding means including an optical fiber for receiving light from said broadband light source, said optical fiber having at least a first selectively located fiber chirp grating defined therein so that different wavelengths of said light from said light source are reflected at unique locations at said fiber chirp grating, said locations corresponding to different selected time delays, thereby providing a wavelength encoded light signal output; and

decoding means for receiving said wavelength encoded light signal output and utilizing said wavelength encoded light signal output to provide a time delayed linear grating as an output therefrom, said decoding means including an acousto-optic deflector for light dispersion at diffraction angles selectable by variation of an input signal.

8. The true time delay generating system of claim **7** wherein said acousto-optic deflector is characterized by large time-bandwidth product and high diffraction efficiency at the 1.55 micron wavelength region.

9. The true time delay generating system of claim **7** wherein said optical fiber includes an array of fiber chirp gratings defined therealong, said decoding means further including a window at an output plane from said acousto-optic deflector for selection of a selected spectrum of said dispersed light as said time delayed linear grating, said selected spectrum corresponding to a selected fiber chirp grating time delays.

10. The true time delay generating system of claim **9** wherein said fiber chirp gratings in said array are sufficient in number so that up to at least about 1000 time delays corresponding to wavelength reflection locations are provided.

11. The true time delay generating system of claim **9** further comprising a plurality of second optical fibers at said delay encoding means each having an array of fiber chirp gratings defined therealong, and multiplexing means associated with said optical fibers so that up to at least about 10,000 time delays corresponding to wavelength reflection locations are provided.

12. The true time delay generating system of claim **9** further comprising amplifying means for optically amplifying said wavelength encoded light signal output, wherein said acousto-optic deflector provides multiple wavelength spectra linearly arrayed at said output plane for selection at said window, and wherein said selection of a selected spectrum at said window is controlled by diffraction angle selection at said acousto-optic deflector.

13. A method for generating true time delays comprising the steps of:

launching broadband light into an optical fiber having a plurality of selectively located fiber chirp gratings therealong to provide a wavelength encoded light signal output;

dispersing said wavelength encoded light signal output at selected diffraction angles to provide multiple wavelength spectra linearly arrayed at an output plane; and

selecting a spectrum from said multiple wavelength spectra at said output plane corresponding to a selected one of said fiber chirp gratings at said optical fiber to thereby provide a selected time delayed linear grating.

14. The method for generating true time delays of claim **13** further comprising the steps of serially selecting different spectra from said multiple wavelength spectra at said output plane corresponding to selected different fiber chirp gratings to selectively provide different time delayed linear gratings.

15. The method for generating true time delays of claim **13** wherein the step of selecting a spectrum includes the step of selectively periodically changing said diffraction angles of dispersion of said wavelength encoded light signal output to serially present selected spectra at an output window at said output plane.

16. The method for generating true time delays of claim **13** further comprising the steps of launching broadband light into a plurality of second optical fibers each having an array of fiber chirp gratings defined therealong so that up to at least about 10,000 time delays can be provided.

17. The method for generating time delays of claim **13** further comprising the step of configuring said fiber chirp gratings so that wavelength chirp ratio is constant within any one of said fiber chirp gratings, with each different said fiber chirp grating having a unique wavelength chirp ratio.

18. The method for generating true time delays of claim **13** wherein the step of dispersing said wavelength encoded light is characterized by provision of a large time-bandwidth product and high diffraction efficiency at the 1.55 micron wavelength region.

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